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BRL'S 50MM HIGH PRESSURE POWDER GUN FOR TERMINAL BALLISTIC TESTING - THE FIRST YEAR'S EXPERIENCE

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The first year's operational experience in the BRL Hypervelocity Range is reported here. A 50mm bore by 120 caliber travel smooth bore high pressure powder gun fires into a radiographic terminal ballistic range through an evacuated blast tank. Fifty-eight shots were fired in 1981, permitting establishment of baseline interior ballistic performance data on in-bore masses from 100 to 635 grams, propelling charge masses from 400 to 1000 grams, and breech pressures to 650 MPa, with 20mm ball powder and a custom 35mm M30 propellant. Velocities up to 2645 m/s were achieved.

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I. INTRODUCTION

This report presents a brief overview for the calender year 1981, of the hypervelocity Terminal Ballistics Research facility (Range 309A) of the Penetration Mechanics Branch (PMB), Terminal Ballistics Division, Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, which is an element of the US Army Armament Research and Development Command, Dover, New Jersey.

It became apparent several years ago that the development of a number of weapon systems would require firing for terminal ballistics data in excess of current ordnance velocities. To meet this requirement, the BRL engaged the University of Dayton Research Institute (UDRI) to design and fabricate a high pressure 50mm smooth bore gun, mount, and blast tank capable of exceeding present ordnance velocities. The gun was delivered and the final report issued in October 1979.[1] Instrumentation and control systems were designed, fabricated, and installed by the PMB hypervelocity team.

Completion and operation of the facility was slowed because of limitations in personnel. However, steady progress was made with the personnel available without cutting corners or compromising standards. The facility was operational in January of 1981.

II. THE FACILITY

The terminal ballistic range consists of the launcher, an evacuated blast tank, a short drift space, and an impact area, with the target housed in a tank. (See Figure 1.) The impact tank mounts a target holder on a roller table. The residual penetrator is stopped inside the tank by a heavy armor steel target butt. The full-diameter access door at the up-range end of the tank is closed for the shot, and a stripping plate stops the sabot petals, while the projectile (and pusher plate and obturator) are admitted through a 200mm diameter hole. Shielding the rest of the room from fragments is only an incidental function of the tank. It is primarily intended to confine dusts and aerosols and prevent their spreading. An exhaust fan discharges to the environment, and absolute filters keep the concentration to an acceptable level. Limited data on sabot discard and aeroballistics is available in the drift space from four orthogonal pairs of 180 kV flash x-rays just down-range from the blast tank's exit diaphragm, a 0.13mm thick by 210mm diameter Mylar@ sheet. Three up-range and three down-range orthogonal pairs of 300 kV flash x-rays are located at the impact tank to record the striking and residual terminal ballistic data.

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[1] *Bauer, D.P., and Nagy, M.D., "Operation Manual for a 50mm Research Gun System," University of Dayton Research Institute Technical Report, UDR-TR-79-80, September 1979 (Contract Number DAAK11-77-C-0027).*

@ *Mylar is a registered trademark of the E.I. Dupont de Nemours Co., Inc.*

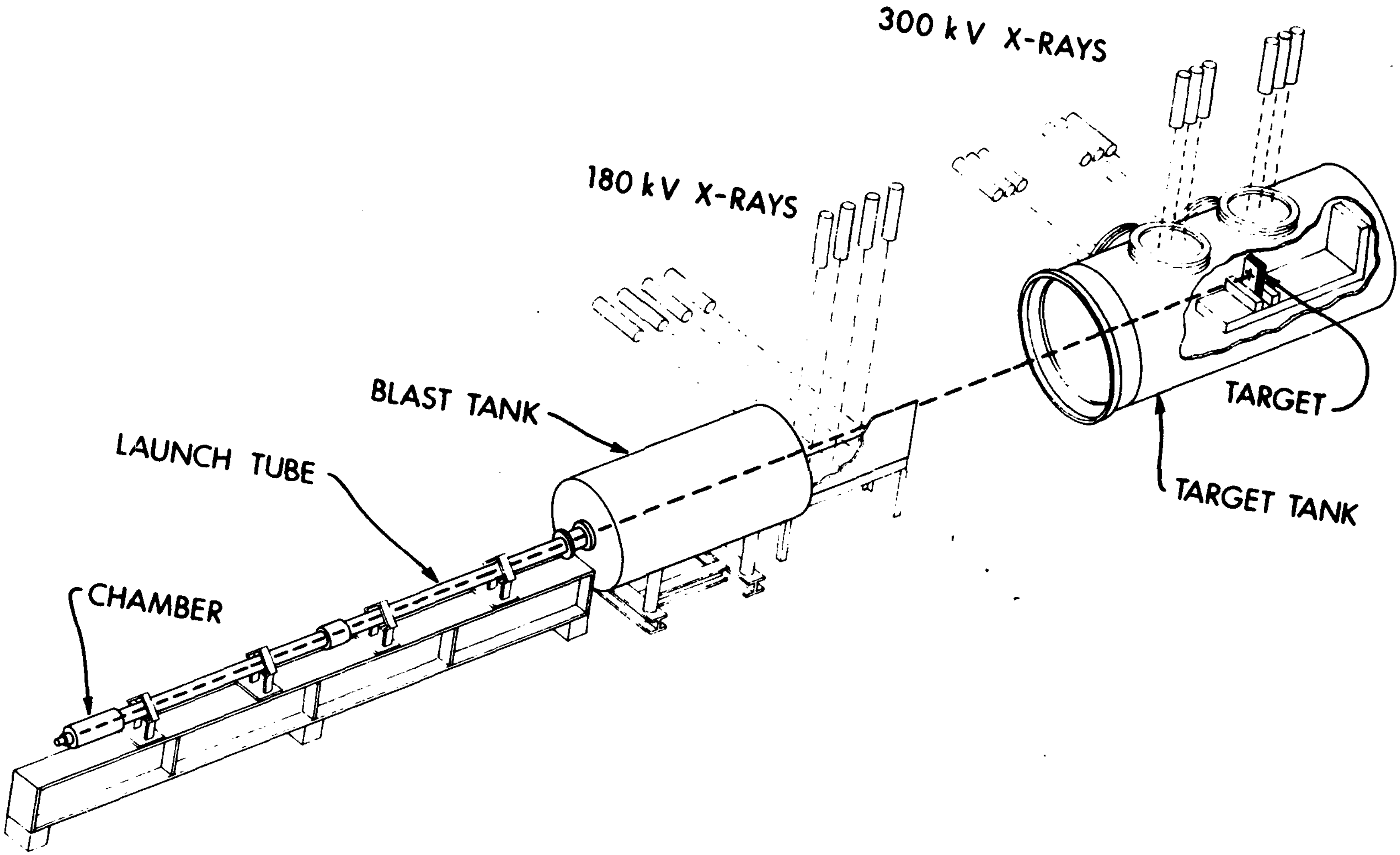


Figure 1. Physical layout of Range 309A. Not shown is the firing console and the flash radiographic instrumentation and pulsers.

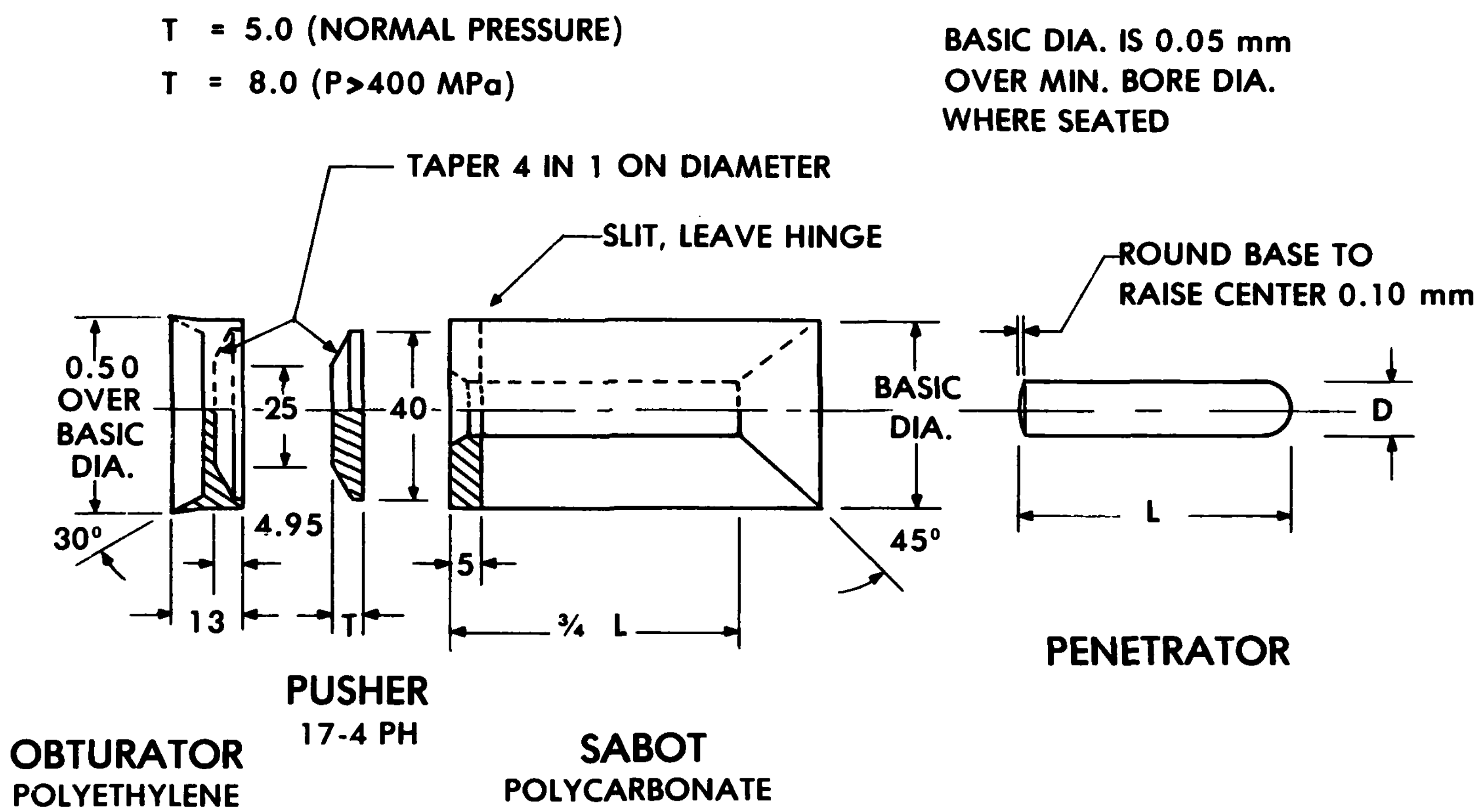


Figure 2. Typical push launch package. Shown in half-section.

Because the facility is one of the few in existence, considerable additional diagnostic instrumentation is included for interior and exterior ballistic work. Pressure taps are available at breech face, rear face of tube (RFT), and four stations along the barrel. Two dual channel Nicolet digital oscilloscopes provide the capability for recording pressure traces from four of these six stations and storing the record permanently on floppy discs. Two copper crusher gages are routinely loaded into the powder chamber at the breech face to provide an independent, redundant pair of peak pressure measurements. An average of the two measurements is stored in a powder data base (resident on an HP9845 desktop computer) and is utilized to obtain pressure and velocity predictions given charge and in-bore mass. Experience has confirmed the copper crusher readings as being reliable and essentially the same as the peaks on the breech face pressure trace.

The gun itself is a nominally 50mm diameter by 6 meter travel (120 calibers) smooth bore powder gun with a large capacity, high pressure, screw-on chamber. High velocities are achieved by saboting a sub-caliber penetrator to minimize the in-bore mass, and by using charge- to in-bore mass ratios from about 2:1 to as high as 8:1. At present, the standard launch package is illustrated in Figure 2, and comprises a simple four-petal laboratory sabot, a pusher disc only slightly under full bore and relieved at its edges to reduce weight, and a thin obturating pad.

The range supervision program currently resides on an HP9830 mini-computer system. This system requires that the pre-shot data be input, the correct interlock status be verified automatically, and the instrumentation and firing line be ready before releasing control to the operator. After the shot, the radiographs can be digitized and the velocity and yaw data reduced by computer and stored into the data base on the magnetic disc mass storage.

At present, a range supervision system is being developed which will supervise and monitor various activities associated with each firing[2]. Programs resident on an HP85 desktop computer will: request, store, and print relevant pre-impact and recovered post-impact data; query as to the range tasks performed prior to simulation and actual firing; initialize and subsequently read counters; test and reduce pressure data from the Nicolet oscilloscopes; through an HP6942A multiprogramer, set delays which will subsequently control the trigger amplifiers, check doors, valves, breakscreens for on/off conditions, and note which x-ray units were pulsed. The radiographs will be digitized utilizing an HP9845 desktop computer (instead of the HP9830) with the Numonics Digitizer. The data retrieved by the HP85 will be sent to the HP9845 for storage on disc. A short summary will be produced for each round and the powder data base will be updated. The oversight functions of the computer should further reduce the chance for data loss due to human error. Of course, should portions of the computer system be inoperative for any reason, the range operations can proceed with minimum interruption using the individual instruments and controls.

[2] *B.E. Ringers and J.J. Spangler, "An Automated Terminal Ballistics Range Supervision System," BRL Memorandum Report in preparation.*

III. INITIAL OPERATIONS

The first order of business was to determine the powder loading curves for the gun, using plastic proof slugs, with or without steel inserts to provide the required in-bore mass. Two propellants were used: a generic ball or spherical rifle powder, and a 1/3 scale experimental M30 propellant used for tank main gun studies by BRL's Propulsion Division. The spherical rifle powder used was first WC870, manufactured by the Olin Mathieson Chemical Corp., salvaged from 20mm cartridges, and later, H870, manufactured by the Hodgdon Powder Company. They are used here interchangeably, and were selected as being about the slowest burning commerical propellant readily available. The M30, though the residue of a custom batch, has a grain size more suited for our 50mm bore and was expected to provide a longer burn duration and hence, lower peak pressures for a given muzzle velocity. Once a skeleton of proof slug shots were out of the way, a variety of penetrator types were fired to check out saboting, while at the same time, providing additional pressure and velocity data for preparing the operating curves for the gun.

There followed a period of unsatisfactory shots. While the M30 seemed to be the better performer, in retrospect it turns out that it was only more tolerant than the 870 of the bad ignition being experienced. The pressure traces, which should normally display a smooth, rapid rise, and then fall away smoothly at a slower rate, instead often showed fluctuations. Not infrequently, the record could be interpreted as being due to pressure waves, where hydrodynamic sloshing of the burning charge causes abnormal local variations in pressure. In some cases, the pressure at the front of the chamber would be at a local maximum, while that at the rear would be at a local minimum. In other cases, the record was more chaotic, with inflections, steps, bumps, peaks, and even spikes arrayed chaotically over the record.

Swollen or burst igniter tubes were the clue that the priming charge was excessive. Consultation with a number of people in the Laboratory's Propulsion Division, followed by experimentation with the ignition, confirmed this. Thin wooden sticks were used as inert simulants for the Benite igniter strands. The 1.5 and 3.0 gram priming charges in use resulted in their being blown violently to the forward end of the tube, blocking the forward spit holes. Comminution of the Benite would increase its burning rate, and explain the excessive internal pressure in the igniter tube. The blocked holes would result in delayed ignition of a portion of the propelling charge, and the resulting extreme pressure gradient could move the charge, possibly breaking some of the propellant grains, as could bursting of the igniter tube. The increase in the surface area of the broken propellant would be reflected in an unusually rapid rise in the chamber pressure, while the decrease in minimum size of the fragments would result in their early burnout, resulting in a subsequent rapid fall of the pressure to a more nearly normal level.

Reduction of the priming charge to 1 gram of Dupont 700X[@] pistol and shotshell powder seems to have eliminated the ignition problems. This case illustrates the well-known observation that once a particularly persistent

[@] *700X is a registered trademark of E.I. Dupont de Nemours Co., Inc.*

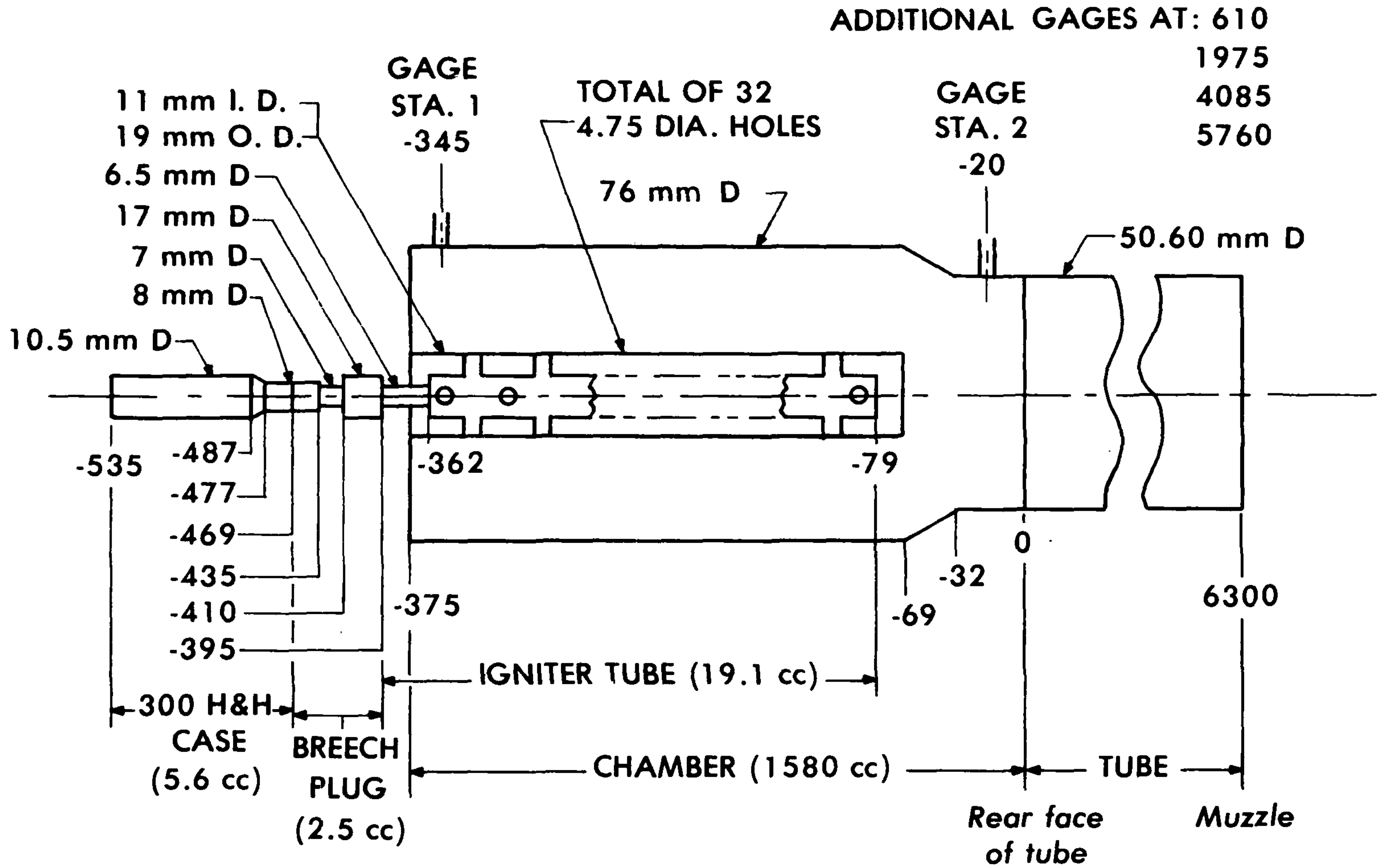


Figure 3. Current wetted ignition train and chamber geometry. Dimensions are in millimeters from rear face of tube and are approximate, while wetted volumes are as measured gravimetrically. Two copper crusher gages displace a total of 24 cc, leaving 1566 cc available for propellant outside the igniter tube.

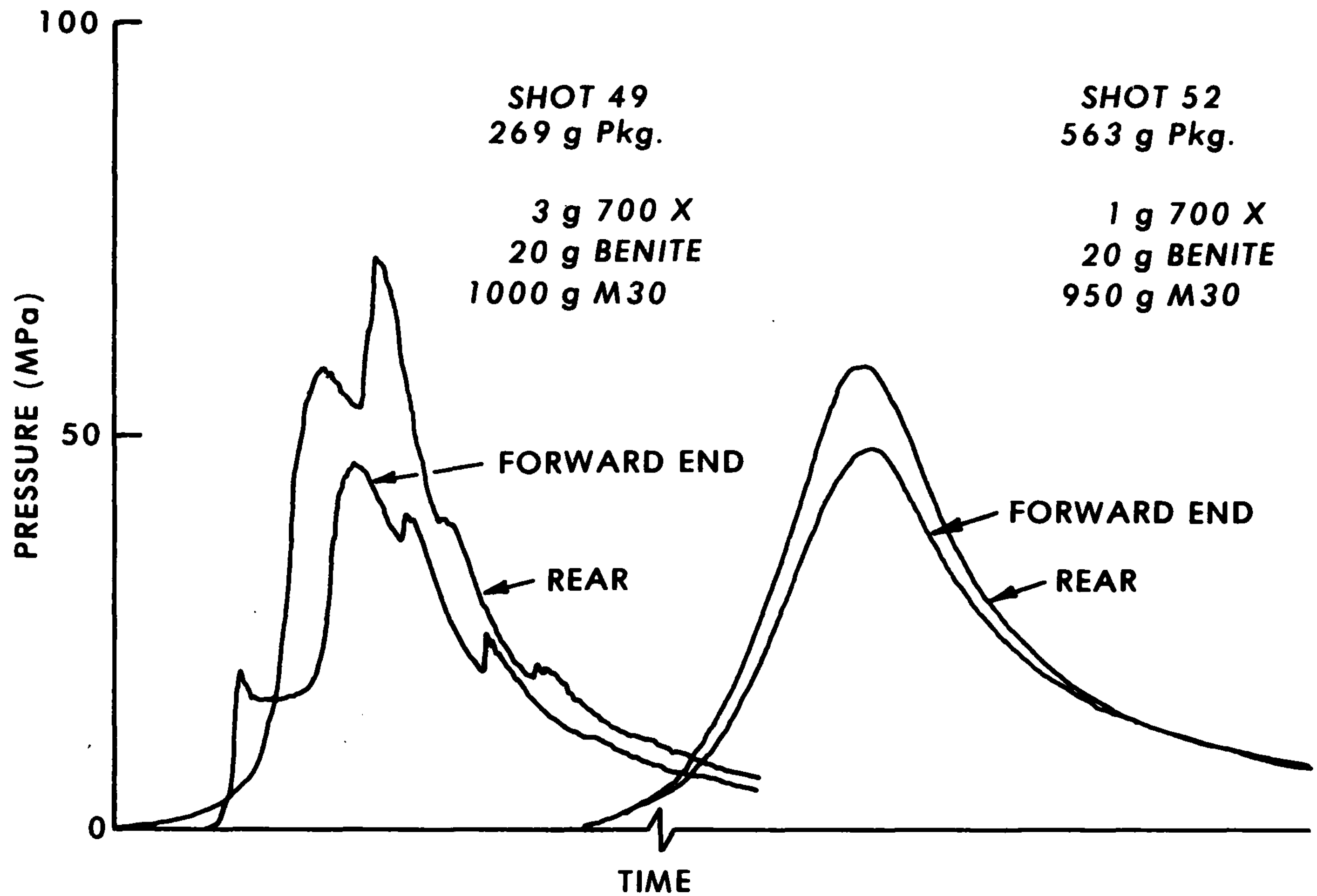


Figure 4. Comparison of bad and good ignition traces.

problem has been solved, the solution was trivial. Figure 3 details the geometry of the wetted volume in the chamber, while Figure 4 presents a pair of pressure traces from just before and after the change to the ignition system.

The bulk of the later shots were fired for three ›ually concurrent purposes: to develop and prove appropriate launch packages; to generate terminal ballistic data (which in turn served to help check out data acquisition, reduction, and storage procedures); and to continue to expand the pressure and velocity predictive data bases for the gun. These data bases are exploited by a portion of the range supervisor computer program, which generates a best-fit prediction of velocity and pressure before the shot. Both are treated as functions of only powder loading and package mass. In an unacceptable shot, the shape of the pressure-time curve cannot be represented by a few parameters (for example, peak pressure and time), and one would not expect the peak pressure or velocity to be representative of a normal shot. Thus, the peak pressure data from shots displaying erratic traces is dropped from the predictive data base to ensure accurate prognostication. The unrepresentative pressure data is nonetheless retained in the experimental results data base and factors into the safety margin that must be allowed to reduce the probability of overstressing the system. The velocity data seems to be much less sensitive to a poor burn, and is only unrepresentative when there is evidence of gross package failure. This is interpreted as being due to the rapidity of burnout relative to the in-bore residence time of the package, the smoothing effect on pressure of the flow down a long tube, and some nebulous relationship connecting these and other factors with the muzzle velocity by way of an integral involving the base pressure-time curve.

A total of 58 shots were fired in 1981, and out of these, there was no a priori reason to reject 50 of them from the velocity predictive data base - 36 with the 870 powder, and 14 for the M30. The 870 data is plotted in Figure 5, and the M30 data is compared with the baseline performance estimate of the 870 in Figure 6. Twelve additional shots with 870 powder were performed by the contractor who supplied the gun, before delivery.[1] Their velocity data was significantly different from ours. though the difference is not worrisome because it is small, and probably due to differences in instrumentation and setup. The breech pressure data was more erratic than the velocity data. Thirty-eight shots could be used for the pressure predictive data base - 27 for the 870 and 11 for the M30. These are plotted in Figures 7 and 8. Comparing the two performances indicates that the M30 subscale propellant provides significantly reduced breech pressures for the same package and charge mass combinations, while comparing the velocities from the two propellants indicates a similar but slight (maybe 100 m/s) advantage to the M30. Thus, it will be used to obtain maximum velocities where extremes of package and charge mass are experienced, by permitting reduced sabot weights.

The terminal ballistic experiments to date have involved two classes of penetrator, a long and a short hemispherically nosed right circular cylinder of soft steel. Except for two multi-plate targets, the targets used were simple armor plate struck at normal incidence. Penetrator masses ranged from 62 grams to 212 grams, and velocities to 2.6 km/s with the lighter packages. Masses and velocities, and target thicknesses were dictated either by the need for specific performance baseline data, or by the threat being simulated. Where the penetration was expected to come within about 50mm of the back face of the target plate in a semi-infinite target a second

plate was added to supply inertial confinement. Material availability sometimes dictated that several plates be used to achieve the thickness desired. In these cases, the mating faces were selected to give good contact, and the plates cleaned of weld spatter or whatnot, though the mill scale was left on. The thinner plate was struck first, but even under these circumstances, plates would separate before perforation, as evidenced by the petalled exit hole in the first plate. The second plate frequently showed no material evacuation, raising the possibility that the termination of penetration tended to be "attracted" by the free boundary. Witness plates were included behind one monolithic target to provide experience with behind-armor debris data collection. In one sense, the product of the year's shooting is a terminal ballistic data base comprising data sheets and radiographs, from which considerably more data can be extracted than is reported here. The results are available to any interested researcher. It is our intention to publish detailed terminal ballistic data reports from time to time as enough logically related data is accumulated.

High yaw plagued most of the shots until the package design was improved in October (shown earlier in Figure 2). Since then, the long rod shots have shown low yaw, while the yaw on the short rod shots have decreased, but not been eliminated. Projecting the yaw back to where it is zero, the problem seems to arise at the ejection of the shot from the muzzle, rather than at the blast tank diaphragm.

Just how much yaw is acceptable has been the subject of a growing amount of debate in the terminal ballistic community as penetrators have grown longer, and velocities higher. To shed some light on the subject, consider the situation shown in Figure 9. If a penetrator of diameter D and length L, yawed at an angle θ, creates an initial hole which has a minimum distance, M, from the penetrator periphery at strike, then the penetrator may proceed into the target undisturbed as long as its periphery clears the initial penetration. The limiting case, where the tail justs touches the hole, is shown in Figure 9a.

It being difficult in general to determine M, one can simplify the problem by assuming that the penetrator nose generates a circular hole of diameter H at some undetermined plane in space, and the limiting yaw occurs when the tail just touches this circle (Figure 9b.). This may be expressed as:

$$\theta = \arctan \frac{(D - H)}{2L} \tag{1}$$

An interesting phenomenon associated with yawed impacts that can be seen in thick targets is that the penetration channel actually inclines in a direction opposite to the striking yaw by an angle, α, determined by the (presumably uniform) relative erosion rates of rod and target as reflected by the ratio of penetration depth to projectile length, P/L (see Figure 9c.). Our steady-state hole diameters are not known before the shot, so that our limiting yaw figures are empirically determined. How much beyond this limit the yaw can be without affecting penetration is undetermined, but the numbers should give a good feel for data quality. The terminal ballistic data is tabulated in the Appendix, in Table A-3. There being relatively few interrelated shots, the data were not plotted. This will be done in next year's report.

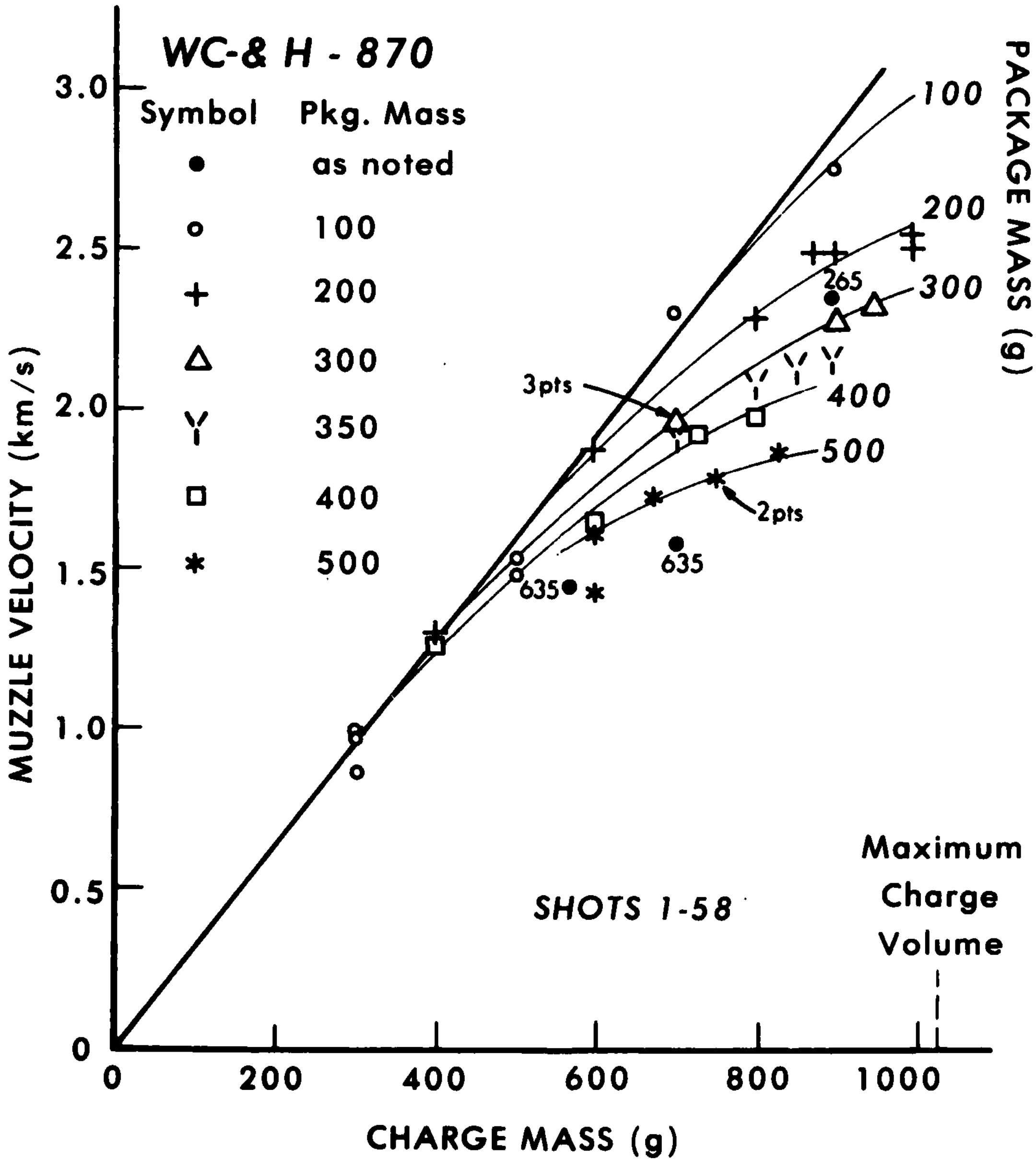


Figure 5. Muzzle velocity versus charge mass for 870 ball propellant.

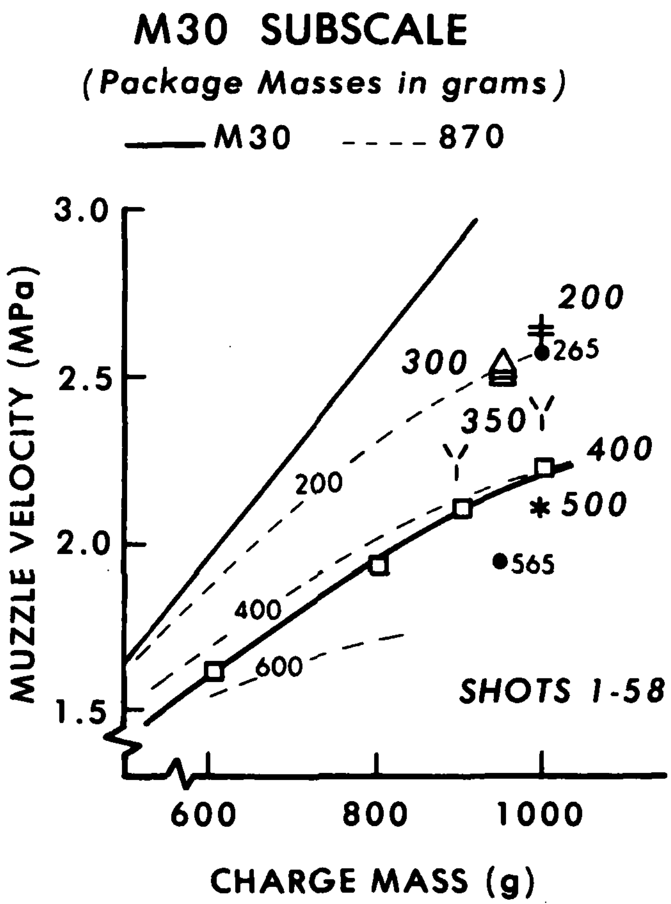


Figure 6. M30 performance (data points) compared with 870 (light broken lines). The M30 propellant can achieve velocities up to about 0.1 km/s over that of the 870 propellant for light packages. There is not enough M30 data to draw any definitive conclusions.

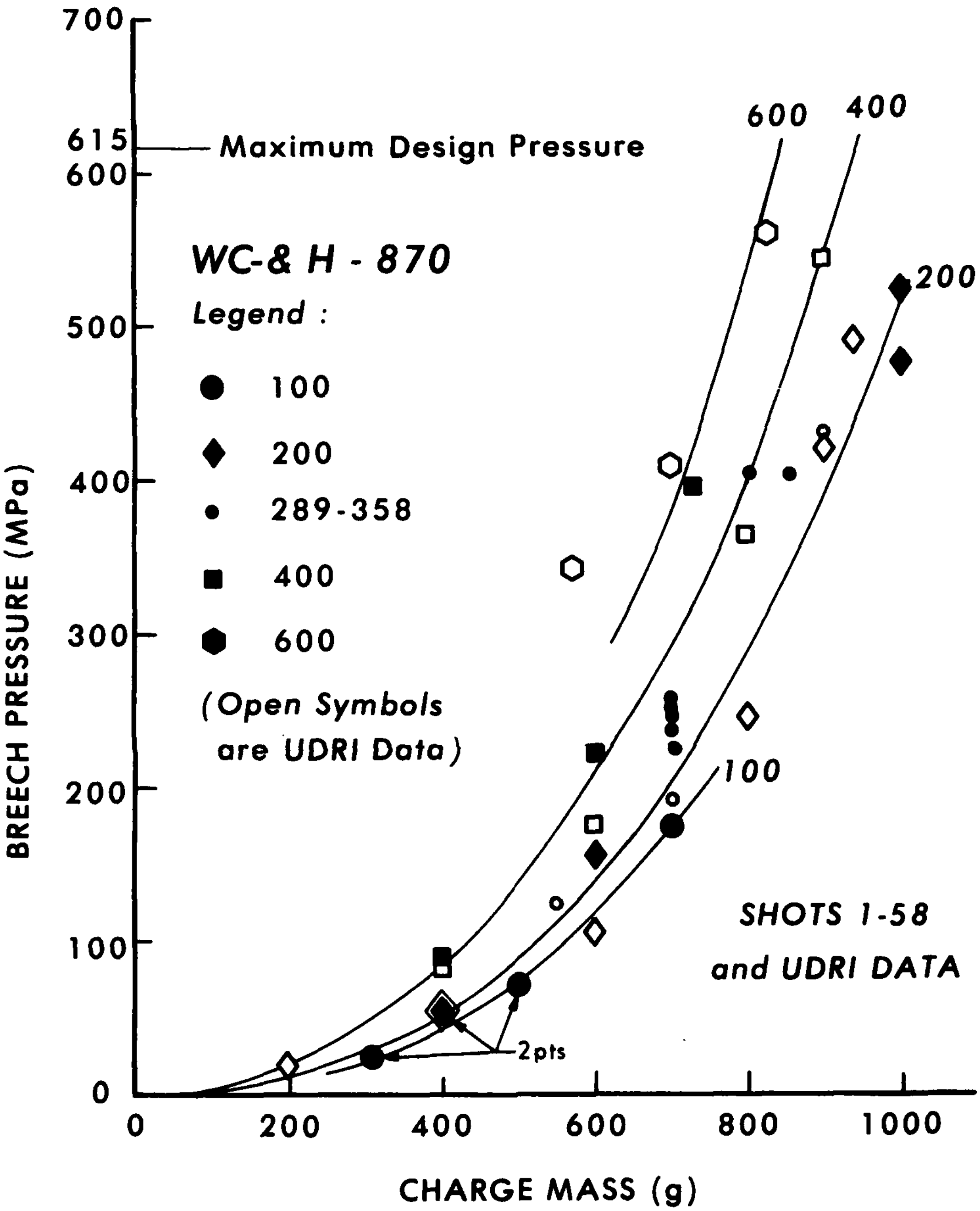


Figure 7. Breech pressure versus charge mass for 870 ball propellant.

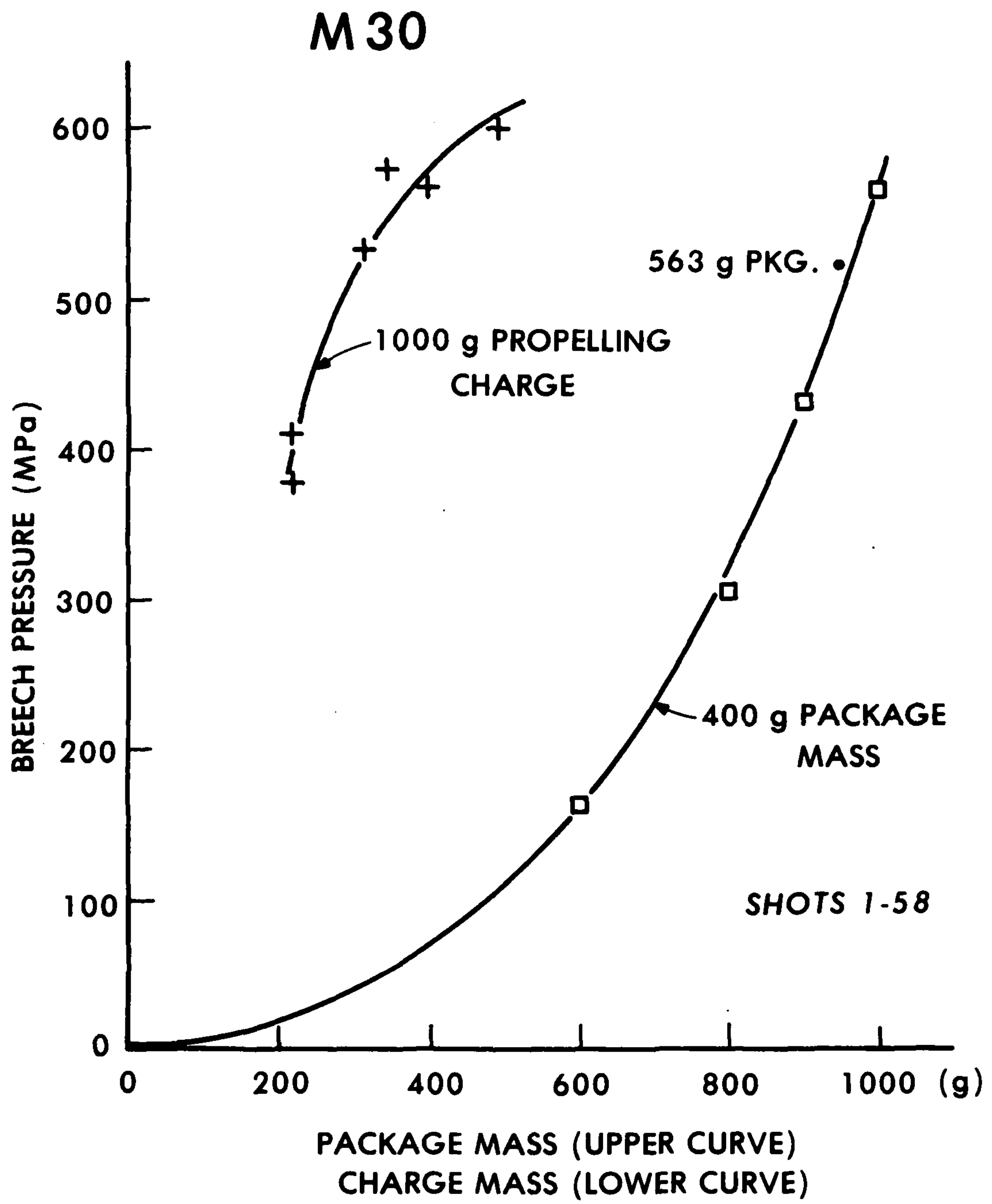
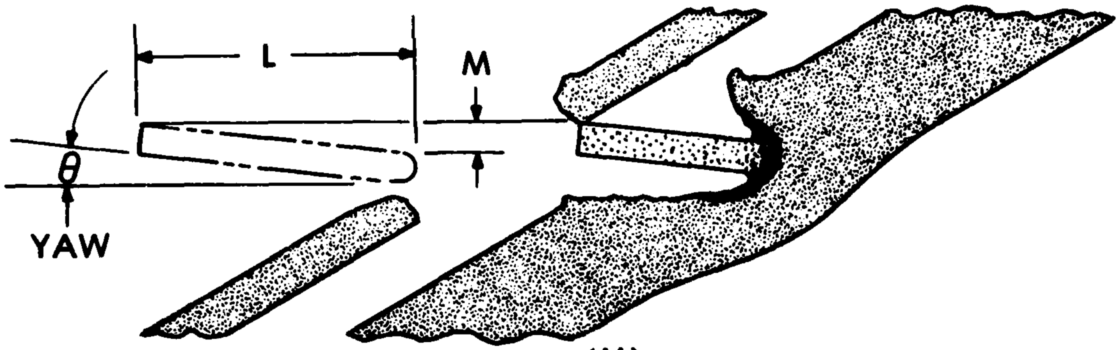
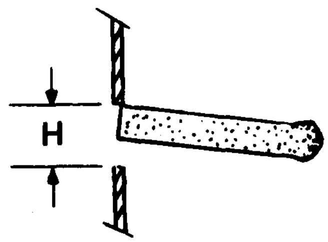


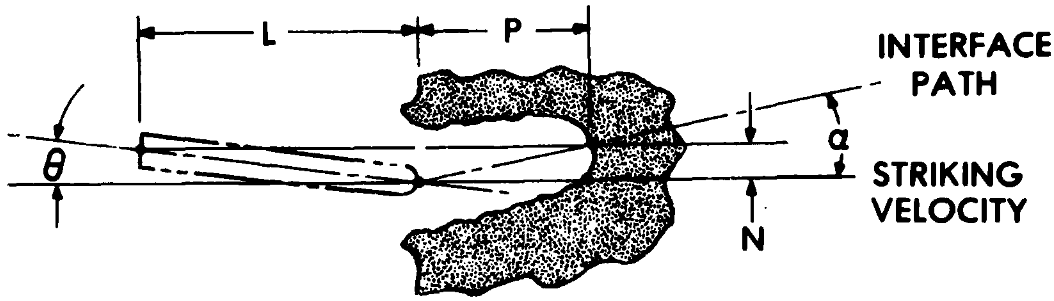
Figure 8. Breech pressure for M30 propellant. Due to the small number of shots, the data is plotted versus charge mass for a 400 gram in-bore mass, and a single 563 gram point, and versus package mass for a 1000 gram propelling charge mass.



9a GENERAL CASE: $\theta = \text{ARCTAN}\left(\frac{M}{L}\right)$



9b UNIFORM HOLE DIAMETER APPROXIMATION: $\theta = \left(\frac{H-D}{2L}\right)$



9c INCLINED PENETRATION CHANNEL DUE TO YAW:

$$\alpha = \text{ARCTAN}\ \frac{N}{P} = \text{ARCTAN}\ \frac{\theta}{P/L} \approx \frac{\theta}{P/L}$$

Figure 9. Critical yaw.

IV. CAPABILITIES

The operating envelope for the gun is generated from the velocity data base for 870 powder in Figure 10. (It is not done for the M30 because only a small amount remains, and we do not intend to use it routinely.) The curves indicate that little gain in velocity could be achieved with a package mass less than 100 grams without reducing chamber volume, so the upper limit on velocity is about 3 km/s (9500 ft/s) with the chamber holding its full one kilogram charge. As package masses increase, velocity continues to be limited by chamber volume until, when the package mass exceeds 500 grams, the chamber pressure reaches its design limit of 615 MPa. Beyond that, the charge mass must be dropped accordingly to stay within bounds.

One translates in-bore mass to projectile mass by invoking a few assumptions about package design, given the projectile geometry dictated by the threat to be simulated and by other practical constraints. The minimum package mass would be limited by overall length and design (25mm is probably a practical lower limit on length). A self-obturating carrier without pusher plate would minimize mass for low pressure launches and light weight projectiles. One could achieve realistic velocities at masses up to several hundred grams for short projectiles such as simulants of explosively projected fragments. As the length to diameter ratio grows, a pusher plate becomes necessary to spread the load on the plastic obturator. 25 to 40 grams are realistic pusher disc masses depending on pressure. Conventional packages of the design shown in Figure 2 have been used to launch 125 gram, L/D 3 steel rods at 2.5 km/s with a 260 gram package mass and the maximum propelling charge.

One of the most pressing areas of concern is to obtain terminal ballistic data on typical anti-tank long rod penetrators at velocities in excess of current ordnance velocities (i.e., greater than 1.5 km/s). Future weaponized penetrators could be expected to span the range of 2 to 6 kg, depending on launch means, have a density of about 18 g/cm^3, and a length to diameter ratio of about 20. One would need to work at some reduced scale to simulate this. (Indeed, isotropic scaling is used frequently to permit obtaining terminal ballistic data on threats from anti-tank rounds to explosively projected fragments -- in any situation where launching a full-scale item exceeds the capacity of the laboratory system, or where reduced cost, short lead time, or better instrumentation dictate.) Armor team experience has shown that there is very good correlation between quarter-scale and full-scale long rod penetrator work when velocity and hardness are identical between full-scale and replica. Less severe scale factors (greater than ¼) should produce even more believable correlation. The isotropically scaled simulant of a full-scale projectile is usually a simple hemispherically nosed right circular cylinder, whose length is that of the original multiplied by the scale factor, and whose diameter is picked to result in a mass that of the original article divided by the scale factor cubed.

Realistic scale factors that could be used are, 1/2, 1/3, and 1/4. The associated package mass is determined primarily by the rod mass, the length of the simulant, (as the bore must be filled with plastic for about 3/4 of the length of the rod) and to some extent by the chamber pressure, which dictates the thickness of the pusher plate. Package weights figured for the range of threat round masses and the three scale factors mentioned are listed in Table 1., as are the expected launch velocities. Changing to a more

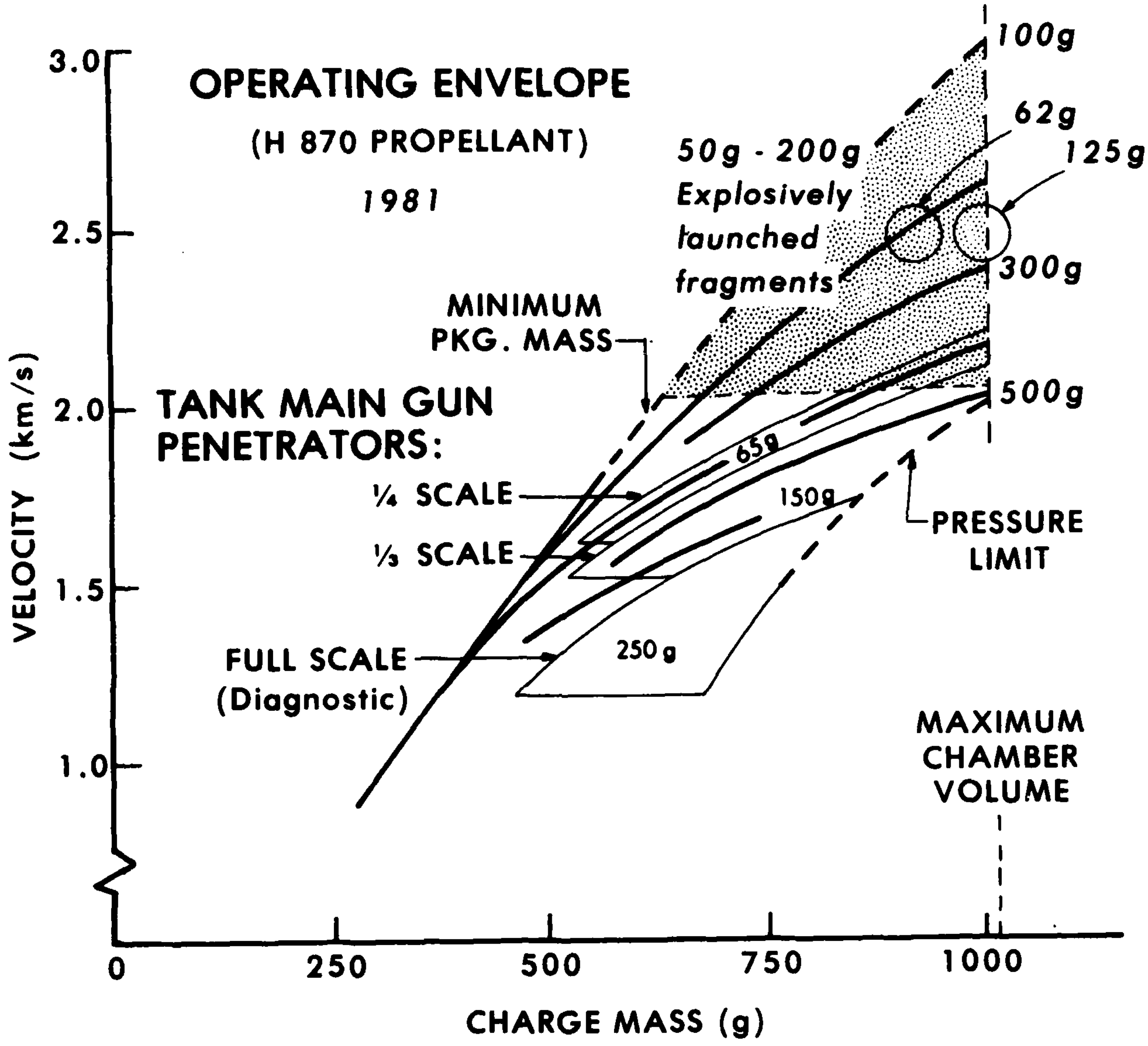


Figure 10. Operating envelope. The gun can profitably fire simulants of tank main gun penetrators at 1/3 and 1/4 scale, as well as short segments of full-scale long rods for target diagnostic purposes. The shaded region at the upper end of the velocity range indicates the area for which the gun is uniquely well qualified. The circles indicate the penetrator weights actually fired at 2.5 km/sec.

sophisticated sabot design such as those seen on real rounds, can be expected to increase these velocities somewhat, but not dramatically.

Table 1. Expected launch velocities from 50mm hypervelocity launcher

L/D 20 high density penetrator of three masses at three reduced scales.

	VELOCITY (km/s)		
Full Scale Mass	1/2 Scale	1/3 Scale	1/4 Scale
2kg	1.8	2.3	2.5
4kg	---	2.1	2.3
6kg	---	1.8	2.2

All traditional terminal ballistic procedures are possible at the facility, e.g., limit measures of armor or penetrator performance by V_{50} or θ_{50} techniques, lethality or vulnerability studies using witness plate or recovery packs, but the most heavily used technique is certain to be the V_s - V_r limit velocity procedure. In this technique, the target configuration is attacked at a number of velocities from below the limit to well above the limit velocity, and the residual velocity is plotted versus the striking velocity. An appropriate form is fit to the data, and the point where the function last has zero residual velocity is called the limit velocity.

For this procedure, as well as behind-armor debris studies, the 300 kV flash radiographic instrumentation is invaluable. Each channel provides an archival record of all six degrees of freedom describing the position and orientation of each rigid particle in the film image for which a distinquishable feature is visible -- three coordinates of position and three of rotation -- with a redundant measurement of the position along the downrange axis of the two features used to compute these six values. In reality, it is not possible to determine the roll without making special preparations of the object before hand. When the position information is coupled with the timing information, this provides a complete kinematic description of the event at each of three times immediately proceeding and three following the impact.

There has not been a long enough period of routine operations to have had an adequate basis for costing, and the rather unusual constitutional, legislative, and administrative strictures on military fiscal matters make it difficult to accurately determine the cost of doing business, so the costs cited should only be treated as very rough estimates. However, they are in line with experience in full-scale and quarter scale range operations.

At present, the full time efforts of an engineer and three technicians are properly charged to the facility. This staffing level is not generous enough to permit the installation and shakedown of the equipment to run concurrently with ballistic testing at a rate which would try the capacity of the system. However, when in routine operation, under the most favorable conditions, and at this staffing level, we should be able to fire about 150 shots per year. Current annual labor and direct overhead rates are approximately $60,000 per person for estimating purposes. The BRL shops can prepare the target and launch package for simple shots in about 10 labor-hours at the same rate, when working in lots of 10 items or more. Test material costs are about $100 more per shot, as are the costs for other supplies and services pro-rated on a per-shot basis. Thus, the cost per shot runs less than $2,000 for labor and materials.

V. FUTURE PLANS

The first order of business is to finish out the range as the instrumentation is received, and to make improvements as initial operations indicate. This involves finishing the control and signal wiring and changing the range supervision program over to the HP 85 minicomputer, installing an optical alignment system in the gun and impact areas, designing a self-aligning hydraulic jacking system to seat the package, and several facility improvements. A packaged exhaust system with a suitably high stack is being procured and will be installed when received, eliminating reingestion of vented propellant gasses.

A spare launch tube must be procured. While the wear in the rear of the present one is not excessive, it is beginning to show numerous small longitudinal cracks, auguring the onset of heat-checking and increased wear rate. At present, after about 75 total shots in the gun, many at less than full charge, the first 200mm of the tube is worn uniformly 0.15mm. No wear-reducing means were employed. Experience with the branch's 26mm smooth bore guns has indicated that as obturation has progessively improved, and as silicone grease has been used in addition to TiO_2-wax as a wear-reducing measure, tube life has risen from about 60 to about 100 shots. The throat geometries and operating pressure ranges on these guns are significantly different, so the lifetimes should not be directly comparable. At the same time, though, we just don't know if there is a whole lot of useful life left in the current tube. We would like to change the design of the replacement tube to that suggested by the University of Dayton Research Institute. The bulk of the wear occurs in the first few hundred millimeters of the tube, so this is made as a sacrificial section, and is replaced as needed, leaving the rest of the tube to be changed only every 500 shots or so. As time permits, design studies are to be done with the goal of possibly replacing the screw-on powder chamber, breech plug, and ignition system with a suitable set of readily available military components where practical, to speed up loading and increase safety. This includes a drop block breech, better powder handling means such as a case, and stock electrical igniters.

Projected operations for the immediate future are to proceed with a number of terminal ballistic programs, and at the same time to finish off the firings to provide a minimum set of data relating pressure and velocity to package mass over the operating regime of the gun. This is to be done by adjusting the sabot, obturator, and pusher geometries used on a terminal ballistic shot to match a needed in-bore weight. Table 2 lists the data

needed at present to complete the data base. The most pressing operational problem is excessive yaw on short packages. We will first change the sabot discard scheme somewhat. If this isn't successful, the next area to be addressed is the muzzle blast region. Currently, the gun has a muzzle extension several bore diameters long and about three times bore diameter. This creates a constriction on the free expansion of the muzzle blast on shot ejection that may contribute to the yaw. If necessary, this extension will be replaced with a launch tube extension opening out abruptly into the evacuated blast tank, mitigating the effect of the muzzle blast on the package to some extent.

Efforts to reduce package weight will continue, in parallel with the design of simulants for real and postulated anti-armor long rod penetrators, which will be launched to demonstrate the system's capabilities. Some form of pusher plate deflector and sabot stripping system will be added, but the optical alignment system is needed to align the deflector to the shot line. Sabot stripping and other conditioning arrangements currently in use in the quarter-scale ranges will also be added.

VI. OUTLOOK

The first year's operation of the 50mm smooth-bore hypervelocity launcher has shown moderate progress, perhaps less than our original optimistic expectations. The experience gained, however, is very valuable, and will be used to improve operations in the current year. A number of problems have been overcome, and the launcher has been demonstrated to be useful for generating a broad range of terminal ballistic data on long rods at conventional and increased velocities, as well as simulated explosively projected fragments. Installation of long-awaited equipment and its shakedown will continue for the first half of the upcoming year, in parallel with terminal ballistic studies, and then it is expected that the facility will be operating essentially full time on research.

Table 2. Velocity data points needed for predictive data base

Package Mass (grams)	Propelling Charge Masses (grams)	Number of Points
	H870 Propellant	
100	800, 1000	2
350	400, 600, 900, 1000	4
400	900, 1000	2
500	450, 900, 1000	3
635	450, 800, 1000	3
		14 points
	M30 Propellant	
200	400, 600, 800	3
400	200, 400	2
565	600, 1000	2
800	400, 500, 600, 700, 800	5
		12 points

APPENDIX

Interior and Terminal Ballistic Data

The detailed interior ballistic data for the year is presented in Table A-1. The "priming" column describes the amount of propellant in the 300 H&H magnum priming case. Its nominal capacity is 3 grams of 870 propellant. The igniter is described in terms of tube geometry and igniter composition and type. The original steel igniter tube was used repeatedly at first, but discarded when it first cracked between two spit holes on shot 8, then swelled ominously on shot 9. Igniter tubes were then cut from M83 military igniters and modified to fit in the breech plug. These essentially lasted only one shot each. Following this, heavy walled brass tubes mimicing the military design were used. The number listed in the column (e.g., 81006-1) is a sketch number describing the geometry. Except for a cut-off one on shot 54 that simulated the original short tube, all were essentially full chamber length. Again, until shot 50, they were damaged enough so that they were usually discarded after one shot as a precaution. The igniter tube in the figure showing the current chamber geometry (Figure 3) is 81006-2. The final priming composition settled on was strands of Benite, a military igniter composition. Typically, 14 full length strands are put into the tube, occupying roughly ½ of the cross-sectional area, and weighing about 20 grams in the referenced tube. The "package fit" column is to be used in the future years to record the force required to seat a projectile in the gun tube. The "maximum chamber pressure" columns describe the average of the pressures measured on two copper crusher gages at the rear of the propelling charge ("Av 2CC Gage @ Sta 1"), and the peak value of the two piezoelectric gage traces, (no matter how bad the trace), one at the rear of the chamber (station 1) and one at the front end of the chamber (station 2).

The column headed "shape" requires some additional clarification. To determine the cause of the unacceptable ignition traces, they were first characterized by the degree of deviation from a smooth curve, and then by the number of these features overlaid on a smooth trace. Figure A-1 gives the name assigned to the series of increasingly bad features, and the abbreviation used in the column. The abbreviations selected are a bit unusual so as to avoid duplicating standard abbreviations used by the authors on other types of data. The peak or maximum in the smooth data is not counted in counting the number of pathological features, as illustrated in Figure A-2. In some instances, the features are on the falling side of the traces. These features are reported as a series of abbreviations. In Figure A-2, the illustrative curve would be called inflection, peak, peak (three features) and be listed as IPP. For only a single feature, one symbol is used, and for two, two.

An asterisk in the column labeled "PPDB" indicates that the peak pressure has not been included in the (peak pressure predictive data base, and similarly for the column labeled "VPDB" (velocity predictive data base). A C1, C2, etc. in the comments indicates a comment that was too lengthy for the column and is listed at the bottom of the particular table.

Table A1. Interior ballistic data for the 50 mm smoothbore. See below and text for abbreviations and conventions.

SHOT	DATE 1981	PRIMING (g)	IGNITER PACKAGE TYPE	IGNITER PACKAGE COMP	IGNITER PACKAGE MASS (g)	PROPELLING CHARGE TYPE	PROPELLING CHARGE MASS (g)	LAUNCH PACKAGE MASS (g)	LAUNCH PACKAGE FIT	AV 2 CC GAGE PRESS (MPa)	PIEZO GAGE TRACES STA 1 PRESS (MPa)	STA 1 SHAPE	STA 2 PRESS (MPa)	STA 2 SHAPE	PPDB	DAMAGE CASE	DAMAGE TUBE	MUZZLE VELOCITY (m/s)	VPDB	COMMENTS
1	Jan 29	1.3 GRAM DUPONT BULLSEYE + 2.0 GRAM OLIN WC870	ORIGINAL STEEL TUBE	BLACK POWDER	8 GRAMS	WC870	300	100.58	MODERATE TO HEAVY INTERFERENCE FIT ON ALL SHOTS		-	-	-	-	*			879		
2	Feb 4					WC870	300	100.68		26	-	-	-	-				999		
3	5					WC870	300	100.54		25	-	-	-	-				983		
4	6					WC870	500	100.63		73	-	-	-	-				1499		
5	9					WC870	500	100.75		74	52	C	45	C				1543		
6	17					WC870	700	100.63		177	186	I	172	NI				2320		
7	19					WC870	900	100.60		532	-----NO RECORD----				*	MB		2757		
8	20					WC870	900	99.56		508	517	PP	372	PP	*	MB	CS	2386	*	
9	24					WC870	400	198.57		55	-----NO RECORD----						CS	1302		Ign. replaced
10	Mar 3		300 MM STEEL TUBE (M83)	BENITE STRANDS	9g	WC870	600	198.53		155	154	II	114	IIP				1873		C1
11	11				20 - 21 GRAMS	WC870	800	198.72		362	348	I	279	I	*			2298		
12	18					WC870	900	199.75		529	-----NO RECORD----				*	RU		2483		
13	24					WC870	400	400.00		90	83	C	76	C				1264		
14	25					WC870	600	400.75		222	NR	NR	200	II				1652		
15	27					M30	600	399.25		165	145	C	165	C				1608		
16	30					WC870	800	400.83		492	414	II	510	FIP	*			1978	*	
17	31					M30	800	399.08		306	310	C	265	C				1926		
18	Apr 1					M30	900	400.87		432	358	C	427	C				2099		
19	2					M30	1000	398.46		575	614	IF	514	IF			BA	2222		
20	4					WC870	800	350.31		506	503	III	369	FII				2070		
21	23					WC870	700	351.11		166	-----NO RECORD----				*			1617	*	C2
22	28	1.5 700X	-1			WC870	700	350.39		326	324	C	283	C				1912		

C1 Gage cases found destroyed in blast tank
C2 Numerous changes to ignition and propelling charge on this shot

Table A1. Interior ballistic data for the 50 mm smoothbore (cont).

SHOT	DATE 1981	PRIMING (g)	IGNITER PACKAGE TYPE	IGNITER PACKAGE COMP	IGNITER PACKAGE MASS	PROPELLING CHARGE TYPE	PROPELLING CHARGE MASS (g)	LAUNCH PACKAGE MASS FIT (g)	AV 2 CC GAGE PRESS (MPa)	PIEZO GAGE TRACES STA 1 PRESS (MPa)	PIEZO GAGE TRACES STA 1 SHAPE	PIEZO GAGE TRACES STA 2 PRESS (MPa)	PIEZO GAGE TRACES STA 2 SHAPE	PPDB	DAMAGE CASE	DAMAGE TUBE	MUZZLE VELOCITY (m/s)	VPDB	COMMENTS
	May																		
23	5	1.5 GRAMS DUPONT 700X	81006-1	BENITE STRANDS	20 - 21 GRAMS	WC870	700	346.56	348	355	C	283	C	*	RU		1929		C3
24	7					WC870	730	390.52	394	-	NN	372	N		RU		1923		
25	11					WC870	700	336.54	338	352	C	324	NN				1960		
26	22					WC870	700	358.35	351	341	I	303	I				1896		
27	29					H870	700	336.76	352	358	IPI	NO GAGES IN STATION TWO					1931		
	Jun																		
28	6					H870	600	503.67	205	200	II						1435	*	C4
29	8					H870	600	489.42	316	314	FF						1617		
30	10					H870	675	479.68	384	369	FPI						1722		
31	12					H870	750	485.20	496	455	PPP			*	RU		1790		
32	16					H870	575	635.10	346	334	NF				RU	BN	1445		
33	18		81006-2			H870	700	635.97	410	403	C						1594		
34	22					H870	825	636.23	561	573	IP				RU		--	*	C5
35	26					H870	750	498.67	451	434	NP			*	RU	BN	1788		
	Jul																		
36	9					H870	825	498.52	478	476	C						1872		
37	9					M30	1000	499.02	615	620	C						2123		
38	28					H870	900	316.79	606	596	FP			*	RU		--	*	C5
39						M30	1000	315.93	532	-	-				RU		NR	*	
	Aug																		
40	4					H870	900	354.66	691/ 798	-	-			*	RU		2156		C6
41	12					H870	900	321.39	783	745	ISS	600	FPS	*	RU	BN	--	*	C5
42	13					M30	900	342.46	471	479	C	407	I		RU		2240		

C3 Package protruded 2 mm into chamber after jacking
C4 Although low pressure and velocity, otherwise a reasonably good shot (blowby?)
C5 Package broke up in bore
C6 Copper crusher pressures were so different that both were listed

Table A1. Interior ballistic data for the 50 mm smoothbore (cont).

SHOT	DATE 1981	PRIMING 700X (g)	IGNITER PACKAGE TYPE	IGNITER PACKAGE COMP	IGNITER PACKAGE MASS	PROPELLING CHARGE TYPE	PROPELLING CHARGE MASS (g)	LAUNCH PACKAGE MASS (g)	LAUNCH PACKAGE FIT	AV 2 CC GAGE PRESS (MPa)	PIEZO GAGE TRACES STA 1 PRESS (MPa)	STA 1 SHAPE	STA 2 PRESS (MPa)	STA 2 SHAPE	PPDB	DAMAGE	DAMAGE TUBE	MUZZLE VELOCITY (m/s)	VPDB	COMMENTS
43	Aug 14	1.5	81006-2	BENITE STRANDS	14	H870	850	344.79	TIGHT EXCEPT 56	504	520	I	448	B		RU	BA	2134		C7
44	24	1.5			21	H870	900	263.30		637/ 681	696	FSI	483	FP	*			2361		C6
45	25	1.5			21	M30	1000	344.69		587	607	I	503	I				2385		
46	26	3.0			21	M30	950	263.50		588	586	BI	424	FP	*	RU		2505		
47	28	3.0			21	M30	950	258.38		729	786	PP	483	SP	*			2512		
48	Sep 9	3.0			20	M30	950	265.43		572	576	BIF	341	BPP	*			2503		
49	21	3.0			20	M30	1000	269.27		636	655	BFF	483	BPP	*			2581		
50	Oct 23	0.5			11	M30	1000	208.81		378	369	C	334	C				2630		C8
51	26	1.0			20	M30	1000	209.38		410	407	C	359	C			NC	2645		
52	Nov 17	1.0			20	M30	950	563.31		524	517	C	490	C			NC	1946		
53	19	1.0			20	H870	875	209.8		530	524	PPP	441	PPP	*		NC	2500		
54	24	0.75	C10	BENITE	20 - 21 g	H870	900	288.5		518	541	II	NR	NR			NC	2284		
55	25	0.75	81006-2			H870	950	286.8		543	565	C	469	C		CR	NC	2330		
56	Dec 7	0.75				H870	1050	502.0		646	672	C	538	II	*	EX	NC	NR	*	C11
57	9	0.75				H870	1000	209.86		477	----NO RECORD----						NC	2545		
58	14	0.75				H870	1000	209.64		529	----NO RECORD----						NC	2545		

C7 Blew off down range end of igniter tube
C8 One second ignition delay
C10 Shortened 81006-2 to yield 81006-3. (Simulates UDRI tube.) Loaded with 10 g Benite.
C11 Loose fit. Package failed in bore. Long rod set back thru 0.2" thick pusher plate.

TABLE A-1. Interior Ballistic Data

Abbreviations and conventions used and not explained elsewhere:

BA - Blown Away

BN - Bent

CR - Crushed or collapsed

CS - Cracked or split

EX - Extruded

MB - Cartridge neck melted and blown away

NC - No change

NR - No record exists or record unreadable (equipment failure, human error, etc)

PF - Primer perforated

RU - Ruptured

-- - Not applicable (no attempt to measure this)

* - Not representative of routine system performance

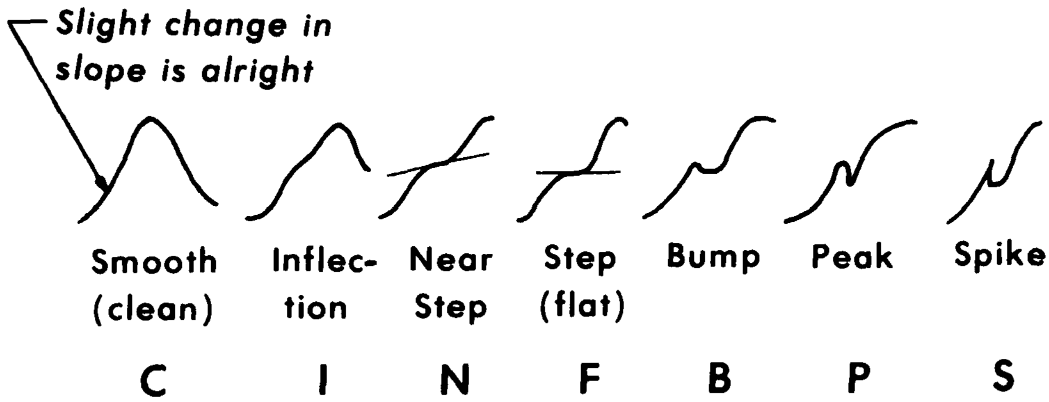


Figure A-1. Characterization of pressure-time traces. Nomenclature is the same whether the feature occurs on the rising or falling side.

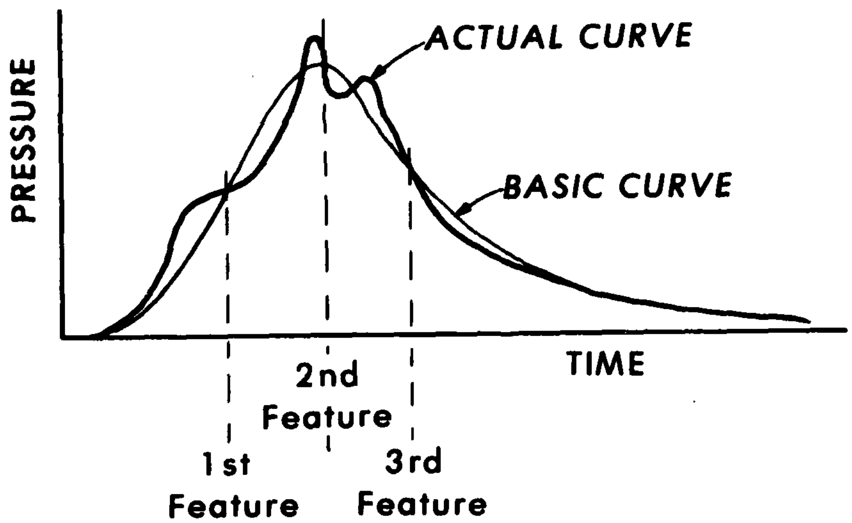


Figure A-2. Illustrative example. These features are superimposed on the basic one in this example. This would be called "Inflection, peak bump", "IPB" in Table A-1.

The terminal ballistic data tabulation was condensed as much as possible by tabulating only those items which changed frequently. The rest of the data is summarized before the tabulation. All of the targets were comprised of rolled homogeneous armor (RHA) for ammunition testing, meeting Military Specification MIL-S-13812. The target plate hardnesses were, at best, measured by a single Brinnel impression to determine if indeed the material was RHA. RHA varies in hardness with thickness within a given range of values. While target hardness definitely influences penetration, the lack of adequate measurement of hardness (a proper Brinnell hardness is the average of 20 numbers) and the exploratory nature of the shots prompted us to merely report the range of check hardnesses experienced for the target thicknesses used and contrast them with the values in the specification. There is no reason to believe that the hardness of the plates checked differs significantly from the nominal value in the specification. Table A-2 presents the data.

Table A-2 Specification and check hardness of RHA used in 1981

Plate Thickness (mm)	MIL-S-13812 Specification Hardness Range (BHN)	Check Hardness Average Value (BHN)	Number of Values
38	293-331	294	2
51	269-311	289	6
76	269-311	286	2
102	241-277	258	19
152	241-277	235	2

There were three classes of penetrator material used in the year's tests. Soft steels comprised an unspecified mild steel, AISI S-7 in its as-received state, or 4340 in its as-received state. The hardness ranged about Rockwell B 100 or the roughly equivalent Rockwell C 20. There were three shots with the rods hardened to Rc 53, which is approximately the hardness used for anti-armor steel long rods. Five shots involved Kennametal W-2*, a tungsten alloy with good terminal ballistic properties. It was supplied to us by the Army Materials and Mechanics Research Center (AMMRC), Watertown, MA. The projectile types are described as a slug in a carrier, a short rod (SR), and a long rod (LR). The slug was a 38mm diameter soft steel cylinder embedded flush with the face of a full bore polycarbonate (PC) cylinder that served as a (non-discarding) sabot and obturator in one. The length of the steel slug was adjusted to give the appropriate in-bore mass. The short rods had a length-to-diameter ratio (L/D) of three, and the long rods, 10. Both had hemispherical

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* *Kennametal W-2 is a trademark of Kennametal Inc., Latrobe, PA.*

noses and flat tails. Where the L/D is different than this, either the rod was upset and bulged at the end on launch, or the nose snapped off. The actual length that struck the target was measured from the radiographs and is reported as striking length. The rods were usually only bulged for a short distance, so nominal diameters are listed. Several masses were tried in the two geometries, but the data is tabulated in the order of increasing L/D first, thickness to diameter ratio (T/D) next, and velocity third, on the assumption that isotropic scaling may be used. In the data tabulation, projectile components are listed in the order in which they were judged to be effective. It is unclear whether the plastic carrier contributed substantially or even significantly to penetration. When the carrier is not listed, it separated from the slug in flight and struck well away from the slug.

Various RHA target arrangements were placed in the range, all at 0^0 obliquity. In a number of them, the behind-target x-ray system was being proofed out be radiographing the projectile in flight, so that the targets were very close to the butt. In some cases, this interfered with the formation of the bulge or perforation. Only a few radiographs unequivocally show enough behind-target debris to measure velocity. No residual penetrator was discernible in any of them. When there was more than one target plate or element (including air space) that participated in the shot performance, these are listed in order in which they were encountered. In one case, witness plates were used to measure location, size, and lethality of behind-armor debris from a perforating short rod.

Abbreviations and conventions used in this tabulation that aren't the same as in the interior ballistic data calculation require explanation. Striking velocity and yaw are taken from the last station before the target at which they were measurable. In shots after number 49, the striking yaw and velocity were extrapolated using average linear velocity decay and yaw growth numbers from all radiographic measurements. The figure for critical yaw (discussed in the text) for slugs and short rods was generated by averaging the hole diameters for all shots with that rod diameter. On long-rod shots, individual hole diameters were used to compute a critical yaw on each shot, as the longer rods are much more yaw-sensitive. Hole diameters are that of the steady-state channel. "Splat" indicates a high yaw hit. Deep penetrations sometimes result in a tapering hole, in which case the dimensions are given in a note. The mass loss measured was reported, but, due to the large size of the plates, is not significant in most cases where there was no perforation. This is indicated by a NS entry. Whether or not the pusher disc hit the penetration is answered with Y for yes and N for no in the next column, and P stands for partial penetration (no perforation) and C for complete penetration (perforation) in the column after that. If there was a partial penetration, the next columns give the penetration depth (P) from the location of the entrance surface of the target and the bulge height, then the ratio of penetration depth to projectile length (P/L) and to diameter (P/D) to aid in plotting the data in dimensionless terms. Where the penetration depth could not be determined from probing an empty hole, the target was sawed in half. Where a residual penetrator could be recovered from a penetration channel, its length and mass were reported as MR and LR.

In the body of the table, figures in parentheses indicate a number that is meaningless for the reason given in the comments column. Columns bearing an entry C followed by a two digit number refer to comments on the right or bottom of the page. A dash indicates that an individual entry would not be applicable at that point, and a D preceding a depth indicates that only a dent was formed (no material was evacuated). In cases where the target plate was heavily bulged, it is possible for the penetration depth to exceed the target thickness, without perforation, and still have a significant amount of material left along the line of fire. Disregards and other shots for which the terminal ballistic data is unavailable are not listed. The data is presented in Table A-3.

TABLE A3. Terminal ballistic data

L/D	T/D	SHOT TYPE	STRIKING LEN (mm)	STRIKING DIA (mm)	STRIKING MASS (g)	STRIKING VEL (m/s)	STRIKING YAW (DEG)	CRIT YAW (DEG)	TGT THK (mm)	HOLE DIA (mm)	TGT ΔM (kg)	PUSHER STRIKE	P OR C	FOR DEP (mm)	PARTIAL PENET. BUL (mm)	P/L	P/D	SHOT NO	COMMENTS
.47	1.34	Slug	17.8	38	169	2111	0.5	35	51	69	1.84	N	C					40	Struck near edge
		PC Carrier			186														
.70	1.0	Slug	26.7	38	236	1575	2.8	25	38	NR	NR	N	C					15	
		PC Carrier			163														
.70	1.0	Slug	26.7	38	237	1875	9.5	25	38	NR	NR	N	C					17	
		PC Carrier			163														
.70	1.34	Slug	26.7	38	238	1939	2.2	25	38	NR	NR	N	(P)	(60)	(25)	NS	NS	16	Plug separation stopped by butt.
		PC Carrier			163														
.70	1.34	Slug	26.7	38	237	2100	7.0	25	38	NR	NR	N	(P)	(75)	(25)	NS	NS	18	Probably a complete
		PC Carrier			163														
.70	1.34	Slug	26.7	38	237	2222	3.2	25	38	NR	NR	N	C					19	No carrier at strike
.70	2.34	Slug	26.7	38	238	1615	13	25	38	NR	NR	N	C	>38		>1.42	>1.0	14	Perfed 1st plate
		PC Carrier			163				51	NR	NR	N	P	NR					
.70	∞	Slug	26.7	38	238	1239	9.5	25	51	NR	NR	N	P	27	8	1.01	.71	13	Flattened bulge on rear of first plate
		PC Carrier			163				51	--	0		-						
									BUTT	--	0		-						
1.0	1.34	Slug	38.0	38	338	1433	6.0	18	51	57	0.84	N	C						
		PC Carrier			163														

TABLE A-3. Terminal ballistic data (cont)

L/D	T/D	SHOT TYPE	S T R I K I N G LEN (mm)	DIA (mm)	MASS (g)	VEL (m/s)	YAW (DEG)	CRIT YAW (DEG)	TGT THK (mm)	HOLE DIA (mm)	TGT ΔM (kg)	PUSHER STRIKE	P OR C	FOR DEP (mm)	PART. BUL (mm)	PENETRATION P/L	P/D	SHOT NO	COMMENTS
2.82	2.49	SR	43	15.25	62.4	2342	23	17	38	41	NR	Y	C					44	C44
2.82	3.34	SR	43	15.25	62.4	2429	18	17	51	43	0.15	N	C					47	C44
2.95	2.61	SR	57	19.30	124.7	2219	20	15	50	48	1.02	Y	C					42	
2.95	2.69	SR	57	19.30	124.8	2342	18	15	52	45	0.68	Y	C					43	
2.95	5.23	SR	57	19.30	124.5	2280	3.3	15	101	C54	0.12	N	P	60	4	1.05	3.11	54	C54
3.01	2.64	SR	58	19.30	124.9	2380	7.6	15	51	53	1.01	Y	C					45	
3.01	2.69	SR	58	19.30	124.8	2330	16	15	52	49	0.51	Y	C	Recovered 445 g spall ring + 132 g other steel fragments loose in tank				55	C55
		Air space							500										
		Aluminum witness plate pair						Left	6.70		34.5 g								
								Right	1.70		15.0 g								
3.02	2.49	SR	46	15.25	62.4	2506	20	17	38	45	0.57	Y	C					46	
3.02	4.98	SR	46	15.25	62.4	2475	46	17	76	40	0.27	Y	P	60	6	1.30	3.93	48	C48
3.02	4.98	SR	46	15.25	62.4	2585	18	17	76	45	4.87	Y	C					49	C48
3.02	5.90	SR	46	15.25	61.8	2500	23	17	38	48	NS	Y	C	47	(9)	0.94	3.08	53	C53
									52	--	0		P	D9	0				
3.02	9.97	SR	46	15.25	61.7	2601	30	17	152	45	0.33	N	P	42	0	0.91	2.75	50	
3.02	9.97	SR	46	15.25	61.7	2645	10	17	152	41	0.13	N	P	58	2.3	1.16	3.80	51	

C44 Tail upset on launch. Struck near edge.
C48 Nearly at limit
C53 Overall P = 47 mm
C54 Channel tapers from 72 to 30 mm dia in 35 mm
C55 Shot to develop behind armor effects measurement procedures

TABLE A-3. Terminal ballistic data (cont)

L/D	T/D	SHOT TYPE	STRIKING LEN (mm)	STRIKING DIA (mm)	STRIKING MASS (g)	STRIKING VEL (m/s)	STRIKING YAW (DEG)	CRIT YAW (DEG)	TGT THK (mm)	HOLE DIA (mm)	TGT ΔM (kg)	PUSHER STRIKE	P OR C	FOR DEP (mm)	PART. BUL (mm)	PENETRATION P/L	PENETRATION P/D	SHOT NO	COMMENTS
9.00	8.00	LR	114.3	12.7	124.2	1790	1.1	3.1	102	25	NR	N	P	73	3	0.64	5.75	31	C31
10.00	6.68	LR	152.4	15.2	214.0	1425	0	2.8	102	30	NS	N	P	77	6	0.51	5.07	32	
10.00	6.68	LR	152.4	15.2	214.9	1582	4.5	3.2	102	32	NR	N	P	55	2	0.36	3.64	33	
10.00	13.24	LR	152.4	15.3	213.9	1946	0.7	3.5	102	34	NR	Y	C	107	(6)	0.70	7.02	52	C52
									101	--	0		P	D2	0				
10.00	8.00	LR	127.0	12.7	124.4	1601	1.1	2.1	102	22	NR	Y	P	68	1	0.54	5.35	29	C29
10.00	8.00	LR	127.0	12.7	124.4	1684	3.1	2.8	102	25	NR	Y	P	72	3	0.57	5.67	30	
10.00	8.00	LR	127.0	12.7	123.7	1785	4.2	2.3	102	23	NS	Y	P	79	5.5	0.62	6.22	35	C35
10.00	8.00	LR	127.0	12.7	1[illegible]3.5	1859	13	3.0	102	26	NS	Y	P	65	3.5	0.51	5.12	36	C36
10.00	8.00	LR	127.0	12.7	123.8	2111	7.3	3.9	102	30	0.15	Y	C					37	C37
Steel rods hardened to HRC 53																			
10.00	9.87	LR	102.6	10.3	65.0	1927	2.8	3.7	102	22	NR	N	P	82	4	0.80	8.04	25	C25
10.00	9.87	LR	101.6	10.2	C26	1895	4.6	3.7	102	25	NR	Y	P	77	2	0.76	7.59	26	C26
10.00	9.87	LR	104.8	10.5	64.9	1910	21	3.7	102	SPLAT	NR	N	P	(42)	0	--	--	27	

C25 LR = 14 mm, MR = 12 g
C26 65 g Nominal L/D 10 rod with integral super-caliber annulus at tail as pusher. M = 90.8 g. Maximum LR = 10 mm
C29 Struck 29 mm from edge
C31 Tail upset on launch. LR = 10 mm, MR = 30 g. Penetrator material formed tube in channel.
C35 LR = 16 mm, MR = 30 g
C36 LR [illegible] mm, MR = 7 g
C37 P[illegible] velocity = 540 m/s
C52 Petalled exit on first plate implies plates separated before perforation of first plate. Petal height 6 mm. Second plate is only dented 2.5 mm deep.

TABLE A-3. Terminal ballistic data (cont)

L/D	T/D	SHOT TYPE	STRIKING LEN (mm)	STRIKING DIA (mm)	STRIKING MASS (g)	STRIKING VEL (m/s)	STRIKING YAW (DEG)	CRIT YAW (DEG)	TGT THK (mm)	HOLE DIA (mm)	TGT ΔM (kg)	PUSHER STRIKE	P OR C	FOR DEP (mm)	PART. BUL (mm)	PENETRATION P/L	PENETRATION P/D	SHOT NO	COMMENTS
AMMRC-supplied Kennametal W-2* Tungsten Alloy Long Rods																			
7.14	13.25	LR	55.0	7.70	46.0	1920	11	4.8	102	17	NR	N	P	80	1	1.45	10.39	23	C23
8.83	13.25	LR	68.0	7.70	65.7	2064	27	--	102	SPLAT	NR	Y	P	(54)	0	(0.79)	(7.01)	20	C20
10.00	13.25	LR	76.2	7.62	65.4	1894	24	--	102	SPLAT	NR	Y	P	(48)	0	(0.63)	(6.23)	24	
10.00	13.25	LR	77.0	7.70	65.0	1616	37	--	102	SPLAT	NR	Y	P	NR	NR	NR	NR	21	C21
10.00	13.25	LR	77.0	7.70	65.0	1895	34	--	102	SPLAT	0.17	Y	P	(40)	0	(0.52)	(5.19)	22	

* W-2 is a trademark of Kennametal, Inc., Latrobe, PA

C20 Tail badly flared
C21 Tail slightly upset
C23 Nose snapped off in-bore, tail stuck in channel entrance

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